2022

AP® CollegeBoard

AP® Biology

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 1

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 1: Interpreting and Evaluating Experimental Results with Experimental Design — 9 points

The binding of an extracellular ligand to a G protein-coupled receptor in the plasma membrane of a cell triggers intracellular signaling (Figure 1, A). After ligand binding, GTP replaces the GDP that is bound to $\mathrm{Gs}\alpha$, a subunit of the G protein (Figure 1, B). This causes $\mathrm{Gs}\alpha$ to activate other cellular proteins, including adenylyl cyclase that converts ATP to cyclic AMP (cAMP). The cAMP activates protein kinases (Figure 1, C). In cells that line the small intestine, a cAMP-activated protein kinase causes further signaling that ultimately results in the secretion of chloride ions (Cl^-) from the cells. Under normal conditions, $\mathrm{Gs}\alpha$ hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

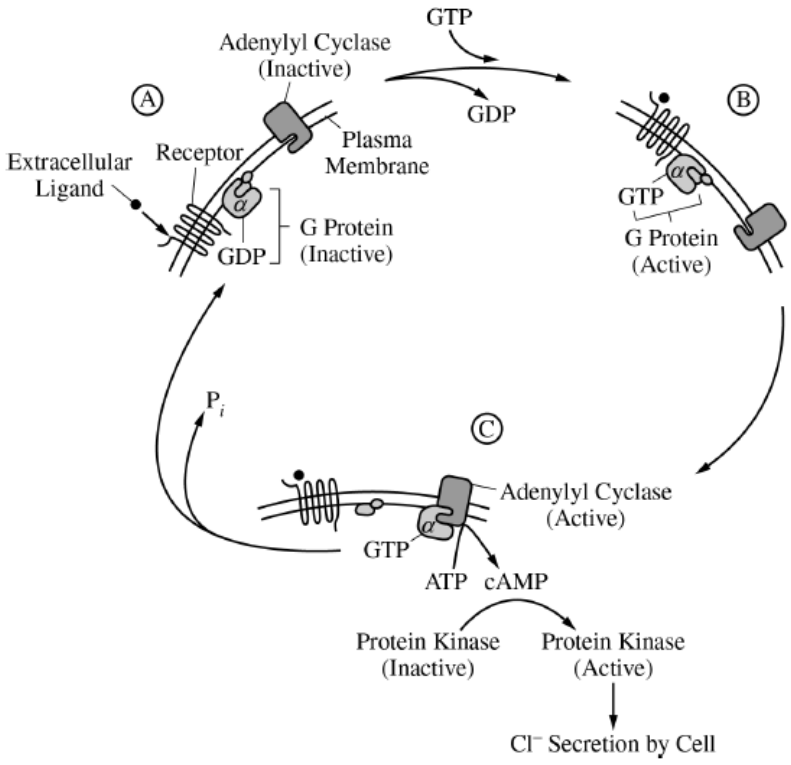

Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

Individuals infected with the bacterium *Vibrio cholerae* experience severe loss of water from the body (dehydration). This is due to the effects of the bacterial cholera toxin that enters intestinal cells. Scientists studied the effects of cholera toxin on four samples of isolated intestinal cell membranes containing the G protein-related signal transduction components shown in Figure 1. GTP was added to samples II and IV only; cholera toxin was added to samples III and IV only. The scientists then measured the amount of cAMP produced by the adenylyl cyclase in each sample (Table 1).

TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	−	−	0.5
II	+	−	10.0
III	−	+	0.5
IV	+	+	127.0

present,+; absent, −

(a) **Describe** one characteristic of a membrane that requires a channel be present for chloride ions to passively cross the membrane. **1 point**

Accept one of the following:

- The interior of the membrane/phospholipid tail is nonpolar.
- The interior of the membrane/phospholipid tail is not charged.
- The interior of the membrane/phospholipid tail is hydrophobic.

Explain why the movement of chloride ions out of intestinal cells leads to water loss. **1 point**

Accept one of the following:

- The space outside of the cells becomes hypertonic/hyperosmotic compared with the cells, so water moves out of the cells.
- The space outside of the cells would have a lower water potential compared with the cells, so water will move out of the cells.

Total for part (a) 2 points

(b) **Identify** an independent variable in the experiment. **1 point**

Accept one of the following:

- The presence or absence of cholera toxin
- The presence or absence of GTP

Identify a negative control in the experiment. **1 point**

Accept one of the following:

- The sample lacking both cholera toxin and GTP /sample I
- The samples that lack cholera toxin /samples I and II
- The sample that lacks cholera toxin but contains GTP /sample II
- The samples that lack GTP /samples I and III

Justify why the scientists included Sample III as a control treatment in the experiment. **1 point**

Accept one of the following:

- (Sample III serves as a control) to compare cAMP production with that of the sample having cholera toxin and GTP /sample IV.
- Comparing sample III and sample IV enables the scientists to evaluate whether the activity of cholera toxin requires GTP/acts via the G protein pathway.

Total for part (b) 3 points

(c)	Based on the data, **describe** the effect of cholera toxin on the synthesis of cAMP. Accept one of the following: • Cholera toxin increases the production of cAMP in the presence of GTP (IV vs II). • Cholera toxin has no effect on the production of cAMP in the absence of GTP (III vs I).	**1 point**
	Calculate the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II. • 1,170% [(127−10)/10 = 11.7 × 100]	**1 point**
		Total for part (c) 2 points
(d)	A drug is designed to bind to cholera toxin and prevent the toxin from crossing the intestinal cell membrane. Scientists mix the drug with cholera toxin and then add this mixture and GTP to a sample of intestinal cell membranes. **Predict** the rate of cAMP production in $\mathrm{pmol\ per\ mg}$ adenylyl cyclase per min if the drug binds to all of the toxin. • The rate will be 10 ($\mathrm{pmol\ per\ mg}$ adenyl cyclase per min).	**1 point**
	In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by $\mathrm{Gs}\alpha$. The scientists claim that cholera toxin will not cause excessive water loss from whole intestinal cells that contain the mutant adenylyl cyclase. **Justify** this claim. • (Even in the presence of the toxin) cAMP will not be produced (by this pathway), the protein kinases will not be activated, and $\mathrm{Cl^-}$ ions will not be secreted (and less water will leave the intestinal cells).	**1 point**
		Total for part (d) 2 points
		Total for question 1 9 points

BEGIN Question 1

Begin your response to **QUESTION 1** on this page. Do not skip lines.

a. A membrane's hydrophobic interior would inhibit charged ions like chloride ions from passing through it. Therefore, a channel is needed to allow chloride ions to pass through. The movement of chloride ions out of intestinal cells lowers the water potential of the cells' external environment (more solute now) & increases the water potential inside the cells (less solute now). Since water moves from areas of high water potential to areas of low water potential, water would move out of the intestinal cells, leading to water loss.

b. An independent variable in the experiment is the addition of cholera toxin. Sample I is a negative control. Scientists included Sample III as a control to observe the impact the addition of GTP has on cAMP production when the cholera toxin is added. Because GTP isn't added in Sample III, scientists can see the impact adding GTP had by comparing it to Sample IV.

c. The cholera toxin dramatically increased the rate of cAMP production in the presence of GTP, with the rate jumping from 10.0 pmol per mg adenylyl cyclase per minute to 127 pmol per mg adenylyl cyclase per minute.

$$\frac{127.0-10.0}{10.0} \cdot 100 = \frac{117.0}{10.0} \cdot 100 = 11.7 \cdot 100 = \boxed{1,170\%}$$

d. The rate of cAMP production would be 10.0 pmol per mg adenylyl cyclase per min if the drug binds to all of the toxin. The intestinal cells won't experience excessive water loss because cAMP won't

GO ON TO THE NEXT PAGE.

Use a pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

Additional page for answering Question 1

Continue your response to **QUESTION 1** on this page. Do not skip lines.

be able to be produced as it's only transformed from ATP when $G_s\alpha$ binds to adenylyl cyclase, which the mutated version doesn't allow. With cAMP unable to be produced, protein kinases won't be activated, meaning Cl^- ions won't be secreted out of the cell. Since Cl^- ions aren't being pumped out, the intestinal cell's water potential will remain lower, meaning there's less water movement out of the ~~loss~~ cell.

GO ON TO THE NEXT PAGE.

Use a pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

0182796

Q5329/3

BEGIN Question 1

Begin your response to **QUESTION 1** on this page. Do not skip lines.

a) Membranes are made up of a phospholipid bilayer that consists of hydrophobic tails. This means that ions cannot pass through without channel proteins. The movement of the ions lead to water loss because of water's affinity for polar molecules as well as osmosis.

b) An independent variable is the presence of GTP. A negative control is Sample 1 when neither GTP or the Cholera Toxin are present. Scientists included Sample III as a positive control to show that cholera alone cannot increase cAMP production.

c) The cholera toxin in the presence of GTP significantly increased the rate of cAMP production. cAMP rate of production increased by 1170% in sample IV.

d) The cAMP production will not change dramatically because the toxin will not be able to function. This claim can be justified by the fact that the Adenylyl Cyclase cannot be activated which means cAMP production will not increase and the Cl^- secretion will not occur due to the inactive protein kinase.

GO ON TO THE NEXT PAGE.

Use a pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

BEGIN Question 1

Begin your response to **QUESTION 1** on this page. Do not skip lines.

(a) The cell membrane is a phospholipid bilayer which does not allow ~~anion~~ large anions, like Cl^-, to diffuse through. A channel needs to use energy to pump the Cl^- which the cell uses water to create which results in a loss of water.

(b) The independent variable is the absence or presence of cholera toxin. The negative control in the experiment is when Gsα hydrolyzes GTP to GDP. The scientist used Sample III as the control because the scientist wanted to know the effects of the cholera toxin which means they need to compare the data to a data that has no altercations which means it has no GTP, but has the cholera toxin.

(c) If GTP is present, then the cholera toxin increases the synthesis of cAMP and if GTP is not present, the cholera toxin has no effect on the synthesis of cAMP.
$\frac{127.0-10.0}{127.0} = 0.921 = 92.1\%$ There was a 92.1% increase in the rate of cAMP produced due to the presence of cholera toxin from sample II to sample IV.

(d) The rate of cAMP Production will be around 10.0 pmol per mg adenylyl cyclase per minute. Because the adenylyl cyclase cannot be activated by Gsα, the ATP will not turn into Amp

GO ON TO THE NEXT PAGE.

Use a pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

Additional page for answering Question 1

Continue your response to **QUESTION 1** on this page. Do not skip lines.

which will not turn into cAMP. This will ensure that the cell does secrete Cl^- because the protein kinase will remain active and because the Cl^- is not leaving the cell, the cell will not lose water.

GO ON TO THE NEXT PAGE.

Use a pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

0000687

Q5329/3

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 1 described a G protein-related signal transduction pathway that stimulates the secretion of chloride ions from intestinal cells. The stimulus of the question then described an experiment designed to determine how cholera toxin affects the pathway and presented experimental results in tabular form.

In part (a) test takers were asked to demonstrate understanding of the structure of cellular membranes (Learning Objective ENE-2.C from the AP Biology Course and Exam Description) and explain why transport of an ion across a membrane results in the loss of water from the cell (Learning Objective ENE-2.H).

Responses to part (b) were expected to demonstrate understanding of the design of the experiment (Science Practice 3.C).

In part (c) responses were expected to describe the effect of cholera toxin, based on the experimental data (Science Practice 4.B) and perform a calculation based on the data (Science Practice 5.A).

Part (d) presented two disruptions: a drug that binds to cholera toxin and a mutation to the gene encoding adenylyl cyclase, an enzyme in the signal transduction pathway. Responses were expected to apply understanding of signal transduction pathways (Learning Objectives IST 3.C and IST 3.D) to predict the effect of the drug (Science Practice 6.E) and justify a scientist's claim about the effect of the mutant enzyme (Science Practice 6.C).

Sample: 1A
Score: 8

The response earned 1 point in part (a) for describing one characteristic as the hydrophobic interior. The response earned 1 point in part (a) for explaining that the space outside the cells will have a lower water potential compared with inside the cells, so water will move out of the cells. The response did not earn a point in part (b) for identifying an independent variable, because "the addition of cholera toxin" does not indicate that only *some* samples received cholera toxin. The response earned 1 point in part (b) for identifying a negative control as sample I. The response earned 1 point in part (b) for justifying that the cAMP production of sample III can be compared with the cAMP production of sample IV to "see the impact adding GTP had." The response earned 1 point in part (c) for describing that cholera toxin increased the production of cAMP in the presence of GTP. The response earned 1 point in part (c) for calculating that the percent change in the rate of cAMP production per minute is 1,170%. The response earned 1 point in part (d) for predicting that the rate of cAMP production would be 10 pmol per mg adenylyl cyclase per min. The response earned 1 point in part (d) for justifying "with cAMP unable to be produced, protein kinases won't be activated, meaning Cl^- ions won't be secreted out of the cell," resulting in less water leaving the intestinal cells.

Sample: 1B
Score: 5

The response earned 1 point in part (a) for describing one characteristic as "a phospholipid bilayer that consists of hydrophobic tails." The response did not earn a point in part (a) because it does not correctly explain why the movement of chloride ions leads to water loss. The response did not earn a point in part (b) for identifying an independent variable because it does not include both the presence *and* absence of GTP. The response earned 1 point in part (b) for identifying a negative control as sample I (and further clarifying that this was the sample where "neither GTP or the cholera toxin are present," although this clarification is not required because "sample I" alone is sufficient). The response did not earn a point in part (b) because the justification is incorrect. The response

Question 1 (continued)

earned 1 point in part (c) for describing that cholera toxin increases the production of cAMP in the presence of GTP. The response earned 1 point in part (c) for calculating that the percent change in the rate of cAMP production per minute is 1,170%. The response did not earn a point in part (d) because it does not predict that the rate of cAMP production is 10 pmol per mg adenylyl cyclase per min . The response earned 1 point in part (d) for justifying that "cAMP production will not increase and the Cl^- secretion will not occur due to the inactive protein kinase."

Sample: 1C
Score: 3

The response did not earn a point in part (a) because it does not correctly describe a characteristic of a membrane that requires a channel to be present. The response did not earn a point in part (a) because it does not correctly explain why the movement of chloride ions leads to water loss. The response earned 1 point in part (b) for identifying the independent variable as the "absence or presence of cholera toxin." The response did not earn a point in part (b) for identifying a negative control. The response did not earn a point in part (b) because it does not compare sample III with sample IV , the sample containing cholera toxin and GTP. The response earned 1 point in part (c) for describing that cholera toxin increases the production of cAMP in the presence of GTP (and further describing that cholera toxin has no effect in the absence of GTP, although this further description is not required, because the point had already been earned). The response did not earn a point in part (c) because it does not correctly calculate the percent change in the rate of cAMP production per minute. The response earned 1 point in part (d) for predicting that the rate of cAMP production is 10 pmol per mg adenylyl cyclase per min . The response did not earn a point in part (d) because it incorrectly justifies that "the protein kinase will remain active" and the "cell will not lose water."